STABILIZER DESIGN FOR A TWO AREA POWER SYSTEM NETWORK

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STABILIZER DESIGN FOR A TWO AREA POWER SYSTEM NETWORK

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

By

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CERTIFICATE

This is to certify that the thesis entitled "**Stabilizer Design for a Two Area Power System Network**", submitted by **Anil Kumar Behera (Roll. No. 109EE0436) and Satender Kumar (Roll. No. 109EE0446)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela. A bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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Dept. of Electrical Engineering
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Professor

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Anil Kumar Behera

Satender Kumar

B.Tech (Electrical Engineering)

ABSTRACT

A power system stabilizer is an ancillary device used for improving stability of otherwise poorly stable power system. It helps to restore the system back to the operating point after disturbances like load changes or faulty situations are withdrawn or smoother transition from one to another operating point.

Originally, power system stabilizers are installed to add damping to local oscillatory modes, which were destabilized by high gain, fast acting exciters. Its property is to provide damping torque to reduce the electromechanical oscillations introduced in the system under disturbances.

We analyze the small signal stability for a power system using linearized model and design a stabilizer for single machine infinite bus system. Then the study is extended for a two area system where small signal and transient stability for both intra-area and inter-area modes is observed.

The simulation is performed using MATLAB package, SIMULINK and Power System Toolbox (PST).

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PSS DESIGN USING PST

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ABBREVIATIONS AND ACRONYMS

PSS	-	Power System Stabilizer
AVR	-	Automatic Voltage Regulator
PST	-	Power System Toolbox

CHAPTER **1**

POWER SYSTEM STABILITY BASICS

1.1 Introduction:

Power system stabilizers have been used for many years to add damping to electromechanical oscillations. PSS essentially act through the excitation system of generators in such a way that a component of electrical torque proportional to speed change is generated. One of the major problems in power system operation is related to small signal instability caused by insufficient damping in the system [2]. For countering these instabilities, the most effective way is to use auxiliary controllers called Power System Stabilizers, which produces an additional damping in the system.

Power system stability may be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to disturbances. Power system stability has been classified as shown in below diagram [1].

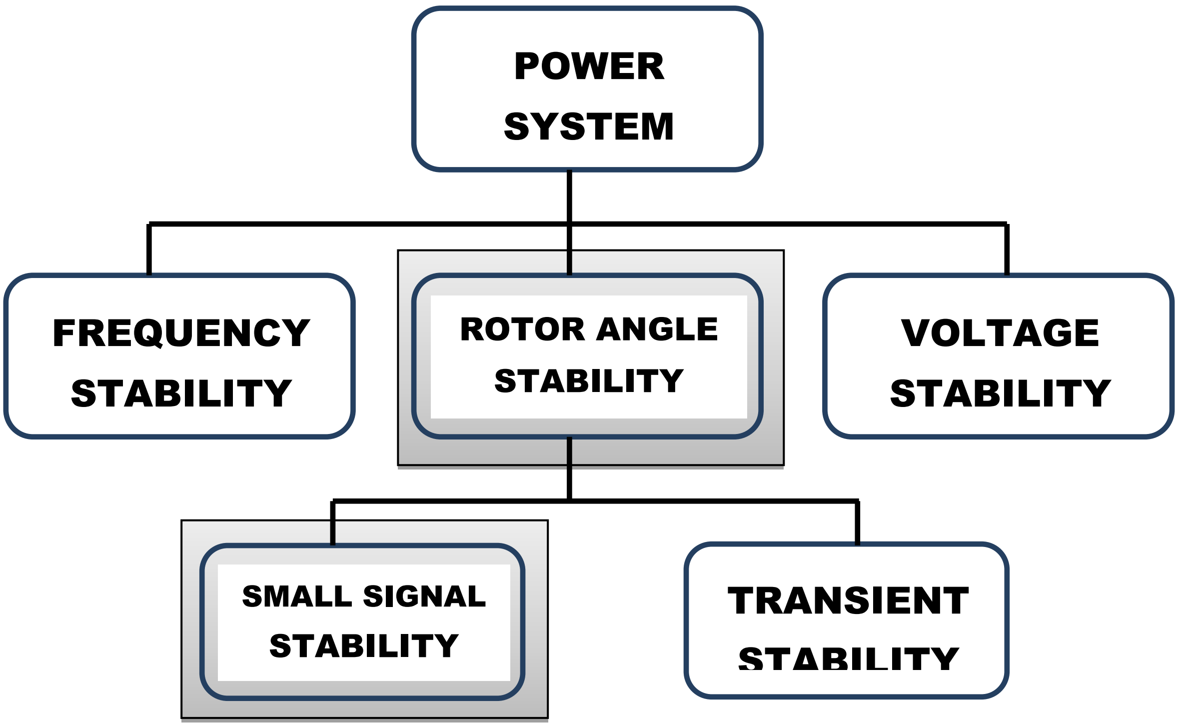

Fig 1. Power-system stability classification [1]

Instability in a power system may be manifested in many different ways depending on the system operating mode and its configuration. Traditionally, to maintain synchronous in the operation is one of the stability problem. Since synchronous machines are very essential for generation of electrical power, a necessary condition for satisfactory operation of the system is that all synchronous machines remain in synchronism. These stability aspects are influenced by the dynamics of generator rotor angles and power angle relationship.

Out of the entire stability problem mentioned above, the specific focus is on small disturbance stability which is a part of rotor angle stability as it causes the maximum instability in power system.

Small signal instability is due to two reasons: (i) steady increase in generator rotor angle due to lack of synchronizing torque, or (ii) rotor oscillations of increasing amplitude due to lack of sufficient damping torque. In today's practical power systems, insufficient damping of system oscillations results in the small signal stability problem. Linear techniques used in small signal analysis provide valuable information about the inherent dynamic characteristics of the power system and assists in its design [2].

1.2 Rotor angle stability:

Rotor angle stability deals with the ability to keep/regain synchronism after being subject to a disturbance in an interconnected power system. In normal system operation, all synchronous machines rotate at the same electrical speed $2\pi f$. The mechanical and electromagnetic torques acting on the rotating masses of each generator balance each other and the phase angle differences between the internal e.m.f.'s of the various machines are constant and it remain in synchronism. Following a disturbance, change in rotor speed is caused due to torque imbalance which leads in loss of synchronism [9].

1.3 Small Signal Stability:

Small-disturbance (or small-signal) angle stability deals with the ability of the system to keep synchronism after being subject to small disturbances. Small disturbances are those for which the system equations can be linearized around an equilibrium point. Small disturbances are always present in fact it is a necessary condition for operating of a power system and it depends on operating point and system parameters. A small disturbance, the variation in electromagnetic torque can be decomposed into synchronizing torque and damping torque. A decrease in synchronizing torque will eventually lead to aperiodic instability (machine \going out of step) and a decrease in damping torque will eventually lead to oscillatory instability (growing oscillations) [9].

CHAPTER **2**

POWER SYSTEM STABILIZER

2.1 Introduction:

A power system stabilizer is used to add a modulation signal to a generator's automatic voltage regulator reference input. The idea is to produce an electrical torque at the generator proportional to speed. Power system stabilizers use a simple lead network compensator to adjust the input signal to give it the correct phase. Common inputs to the stabilizer are generator shaft speed, electrical power or accelerating power, or terminal bus frequency. The input is first passed through a high pass filter (in power systems terms the filter is termed a washout filter) so that the input's steady state value is eliminated. Then the signal coming from washout filter is passed through a torsional filter which filters out the high frequency oscillations due to the torsional interactions of the machine. A typical power system stabilizer block diagram is shown in figure below [2].

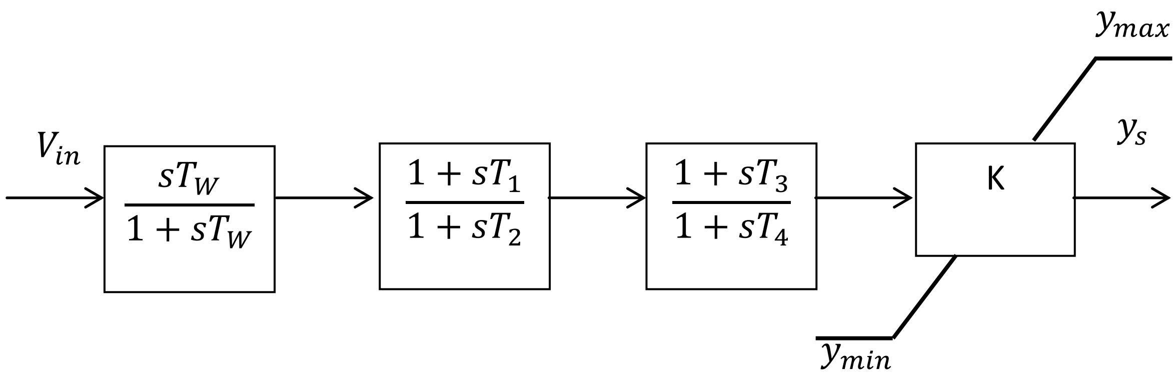

Fig 2. Block Diagram of a typical Power system stabilizer [2]

The problem of power system stabilizer design is to determine the parameters of the stabilizer so that the damping of the system's electromechanical modes is increased. This must be done without adverse effects on other oscillatory modes, such as those associated with the exciters or the shaft torsional oscillations. The stabilizer must also be designed so that it has no adverse effects on a system's recovery from a severe fault. Some of the most recent power system stabilizers have additional lead/lag blocks. Older power system stabilizers may have only a single lead/lag block, this is normally too restrictive for the adequate stabilization of both local and inter-area modes [2].

In our PSS model we have taken washout filter, torsional filter and lead/lag compensator whose purpose and transfer functions are explained below:

2.2 <u>WASHOUT FILTER:</u>

Washout filter is basically a high pass filter with zero dc gain. This filter is provided in PSS to cut-out the PSS path during the steady state. For simulation we have taken the filter as a transfer function model of [1]

$$F(S)=\frac{10s}{10s+1}$$

2.3 <u>TORSIONAL FILTER:</u>

Torsional filters out the high frequency oscillations of the system which are caused due to the torsional interactions of the alternator. For simulation, we have taken the transfer function model of this filter as [1]

$$Tor(s) = \frac{1}{1+0.06s+0.0017s^2}$$

CHAPTER **3**

STATE SPACE MODEL OF A SINGLE MACHINE INFINITE BUS SYSTEM

3.1 Introduction:

The objective here is to study the small-signal performance of a single machine connected to a large system through transmission lines. The configuration of a general system is shown in Fig 3. For purpose of analysis, the system of Fig 2. may be reduced to the form of Fig 4.by using Thevenin's equivalent of the transmission network external to the machine and adjacent transmission [1].

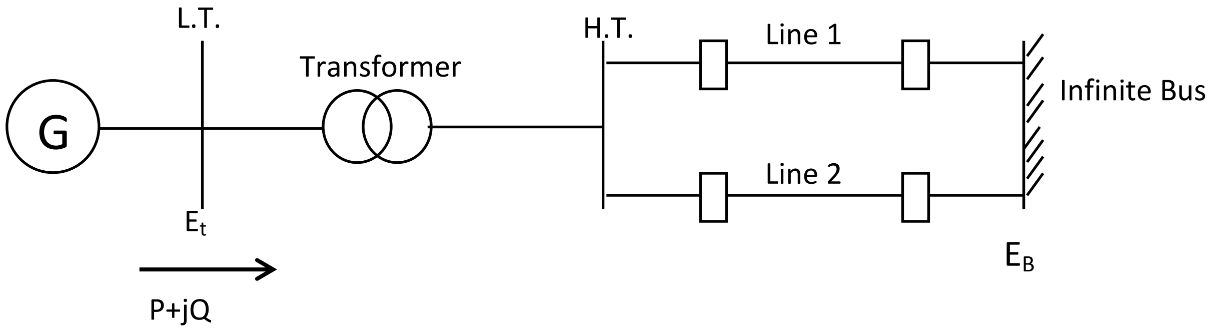

Fig 3. General Configuration of Single Machine Infinite Bus System [1]

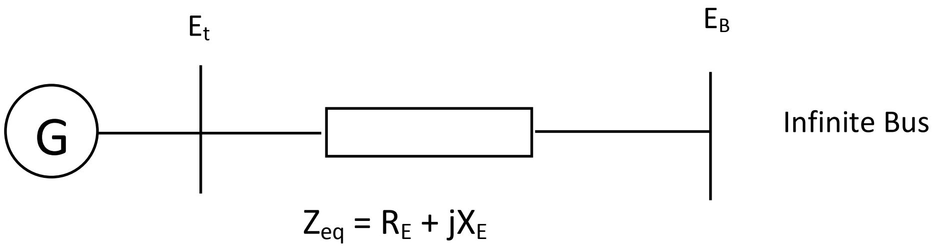

Fig 4. Equivalent System [1]

Because of the relative size of the system to which the machine is supplying power, the dynamics which are associated with the machine will cause virtually no change in frequency of Thevenin's voltage E_B and in system voltage. For any given system condition, the magnitude of the infinite bus voltage E_B remains constant when the machine is perturbed. However, as the steady-state system conditions change, the magnitude of E_B may change, representing a changed operating condition of the external network [1].

3.1 Generator Classical Model

The following model and analysis has been taken from Kundur's book and the same can be found there. The generator represented by classical model with all resistance neglected, the system representation is as shown in Fig 5.

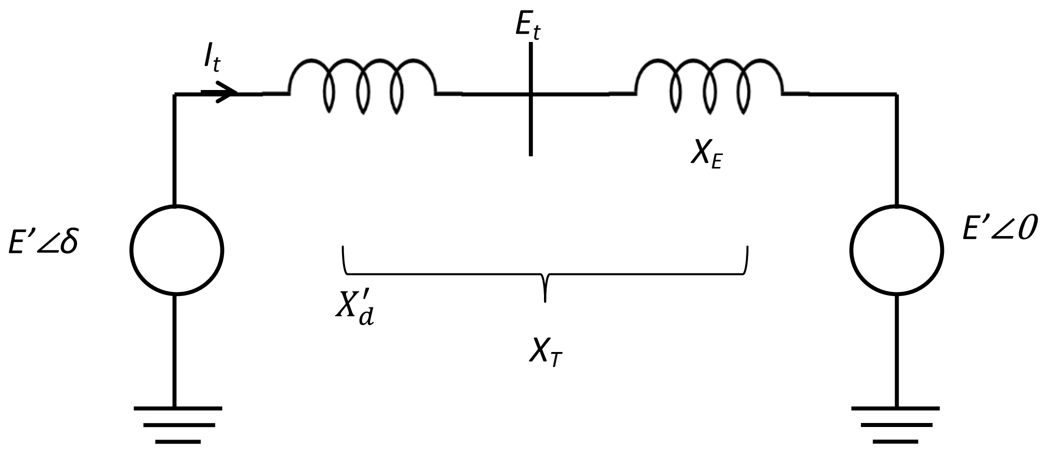

Fig 5. Classical model representation of generator [1]

Here **E**' is the voltage behind $\mathbf{X_d}$**'.** Its magnitude is assumed to remain constant at the pre-disturbance value. Let δ be the angle by which **E'** leads the infinite bus voltage E_B. As rotor oscillates, δ changes during a disturbance.

With E' as reference phasor, we can write the following equations from Fig 4.

$$\overline{E'} = \overline{E_{t0}} + jX_d'\overline{I_{t0}} \qquad (1)$$

$$X_T = X_d' + X_E \qquad (2)$$

$$I_t = \frac{E'\angle 0^o - \angle < -\delta}{jX_T} = \frac{E' - E_B(\cos\delta - j\sin\delta)}{jX_T} \qquad (3)$$

The complex power behind X_d' is given by

$$S' = P + jQ' = \overline{E'}\overline{I_t}^* \qquad (4)$$

$$= \frac{E' E_B \sin\delta}{X_T} + j\frac{E'(E' - E_B\cos\delta)}{X_T} \qquad (5)$$

With stator resistance neglected, the air-gap power (**P**$_e$) is equal to the terminal power (**P**). In per unit, the air gap torque is equal to the air gap power.

Hence,

$$T_e = P = \frac{E' E_B}{X_T} \sin\delta \tag{6}$$

Now Linearizing it about an initial operating condition represented by $\delta = \delta_0$ yields

$$\Delta T_e = \frac{\partial T_e}{\partial \delta}\Delta\delta = \frac{E' E_B}{X_T} \cos\delta_o\,(\Delta\delta) \tag{7}$$

The equations of motion in per unit is given by

$$\frac{d\Delta\omega r}{dt} = \frac{1}{2H}\left(T_m - T_e - K_D \Delta\omega_r\right) \tag{8}$$

$$\frac{d\delta}{dt} = \omega_0 \Delta\omega_r \tag{9}$$

Where $\Delta\omega_r$is the per unit speed deviation, δ is rotor angle in electrical radians, ω_0 is the base rotor electrical speed in radian per second.

Linearizing equation 8 and substituting for ΔT_e given by equation 7,

We get

$$\frac{\mathrm{d}\Delta\omega \mathrm{r}}{\mathrm{dt}} = \frac{1}{2\mathrm{H}}\left[\Delta \mathrm{T_m} - \mathrm{K_S}\Delta\delta - \mathrm{K_D}\Delta\omega_\mathrm{r}\right] \tag{10}$$

Where K_S is known as the synchronizing torque coefficient given by

$$K_S = \left[\frac{E' E_B}{X_T}\right] \cos\delta_0 \tag{11}$$

Linearizing equation 9, we have

$$\frac{\mathrm{d}\Delta\delta}{\mathrm{dt}} = \omega_0 \Delta\omega_r \tag{12}$$

vector-matrix form is obtained using equations 10 and 12

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_r \\ \Delta\delta\end{bmatrix} = \begin{bmatrix} -\frac{K_D}{2H} & -\frac{K_S}{2H} \\ \omega_0 & 0 \end{bmatrix}\begin{bmatrix}\Delta\omega_r \\ \Delta\delta\end{bmatrix} + \begin{bmatrix}\frac{1}{2H} \\ 0\end{bmatrix}\Delta T_m \tag{13}$$

This is of the form $\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu}$**.** The elements of the state matrix A are seen to be dependent on the system parameters K_D, H, X_T, and the initial operating condition represented by the values of E' and δ_0 . The block diagram representation shown in Fig 6.can be used to describe the small- signal performance.

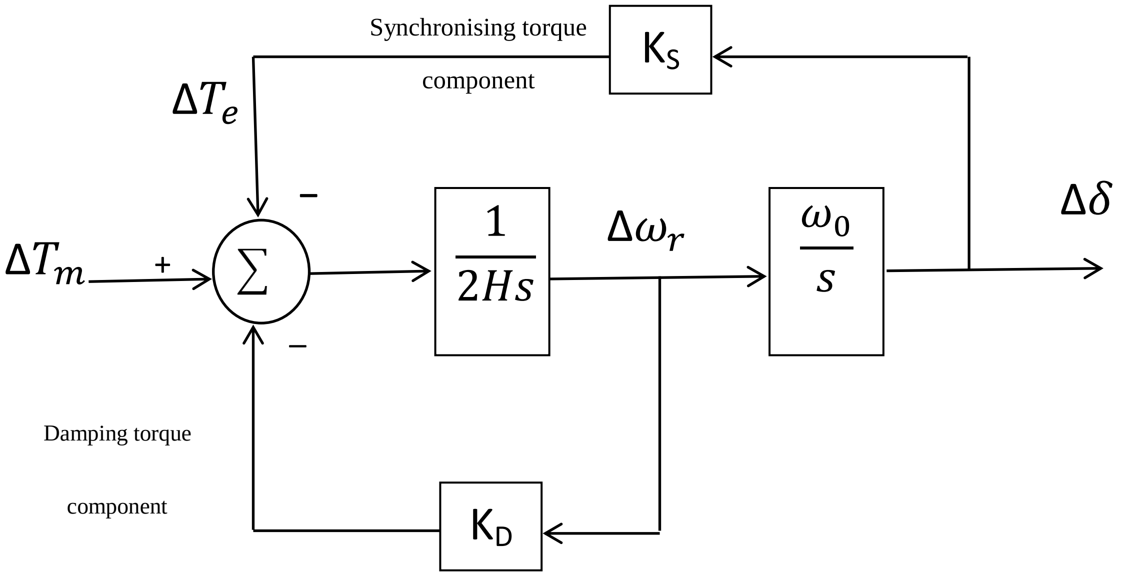

Fig 6. Block diagram of a single-machine infinite bus system with classical generator model [1]

Where,

K_S = synchronizing torque coefficient in pu torque/ rad

K_D = damping torque coefficient in pu torque/pu speed devition

H = inertia constant in MWs/MVA

$\Delta\omega_r$= speed deviation in pu = $(\omega_r - \omega_0)/\omega_0$

$\Delta\delta$ = rotor angle deviation in elec. Rad

S = Laplace operator

ω_0 = rated speed in elec. rad/s = $2\pi f_0$

From block diagram of Fig 6., we have

$$\Delta\boldsymbol{\delta}=\frac{w_0}{s}\left[\frac{1}{2Hs}\{-K_S\Delta\delta - K_D\Delta w_r + \Delta T_m\}\right]$$

$$=\frac{w_0}{s}\left[\frac{1}{2Hs}\left\{-K_S\Delta\delta - K_D s\frac{\Delta\delta}{w_0} + \Delta T_m\right\}\right] \qquad (14)$$

Rearranging, we get

$$s^2(\Delta\delta)+\frac{\boldsymbol{K_D}}{\boldsymbol{2H}}s(\Delta\delta)+\frac{K_S}{2H}\,\omega_0\Delta\boldsymbol{\delta}=\frac{\boldsymbol{\omega_0}}{\boldsymbol{2H}}\Delta T_m \qquad (15)$$

Therefore, the characteristic equation is given by

$$s^2+\frac{K_D}{2H}s+\frac{K_S}{2H}\,\omega_0=0 \qquad (16)$$

This is of the general form

$$s^2+2\zeta\omega_n s+\omega_n{}^2=0 \qquad (17)$$

Therefore, the undamped natural frequency is

$$\omega_n=\sqrt{\frac{K_S}{2H}\omega_0}\ rad/s \qquad (18)$$

and the damping ratio is

$$\zeta = \frac{1}{2}\frac{K_D}{2H\omega_n}$$

$$=\frac{1}{2}\frac{K_D}{\sqrt{K_S 2H\omega_0}} \qquad (19)$$

As the synchronizing torque coefficient K_S increases, the natural frequency increases and the damping ratio decreases. An increase in damping torque coefficient K_D increases the damping ratio, whereas an increase in inertia constant decreases both ω_n and ζ.

CHAPTER **4**

SMALL SIGNAL MODEL OF A TWO AREA SYSTEM USING PST

4.1 Introduction:

Small signal stability means the stability of a dynamic system about the operating point to small disturbances. Small signal stability is tested by linearizing the system's dynamic equations about a steady state operating point to get a linear set of state equations

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

where A is the state matrix; B is the input matrix; C is the output matrix ; D is the feed forward matrix; x is the state vector and u is the input [8].

Here we are using Power System Toolbox (PST) for linearization which is performed by calculating the Jacobian numerically. Here it has the advantage of using identical dynamic models for both small signal stability and transient stability. However, some losses of accuracy occurs, particularly in the zero eigenvalue which is characteristic of most inter-connected power systems. In PST, initially states are determined from model initialization, and then a small perturbation is applied turn by turn to each state [8].

A single driver, **svm_mgen** is provided in PST for small signal stability and for the transient stability simulation driver **s_simu** is provided.

4.2 Two Area System Model Specifications

The following data and model has been taken from Kundur's book. The system consists of a weak tie which connects two similar areas. Each area have two coupled units, each having a rating of 900 MVA and 20 kV. The generator parameters in per unit on the rated MVA and kV are as follows:

$X_d = 1.8$ $X_q = 1.7$ $X_l = 0.2$ $X'_d = 0.3$ $X'_q = 0.55$

$X''_d = 0.25$ $X''_q = 0.25$ $R_a = 0.0025 T'_{d0} = 8.0s$ $T'_{q0} = 0.4s$

$T''_{d0} = 0.03s$ $T''_{q0} = 0.05s$ $A_{sat} = 0.015$ $B_{sat} = 9.6$ $\Psi_{T1} = 0.9$

$K_D = 0$

The two-area system is shown below in Fig 7. [1].

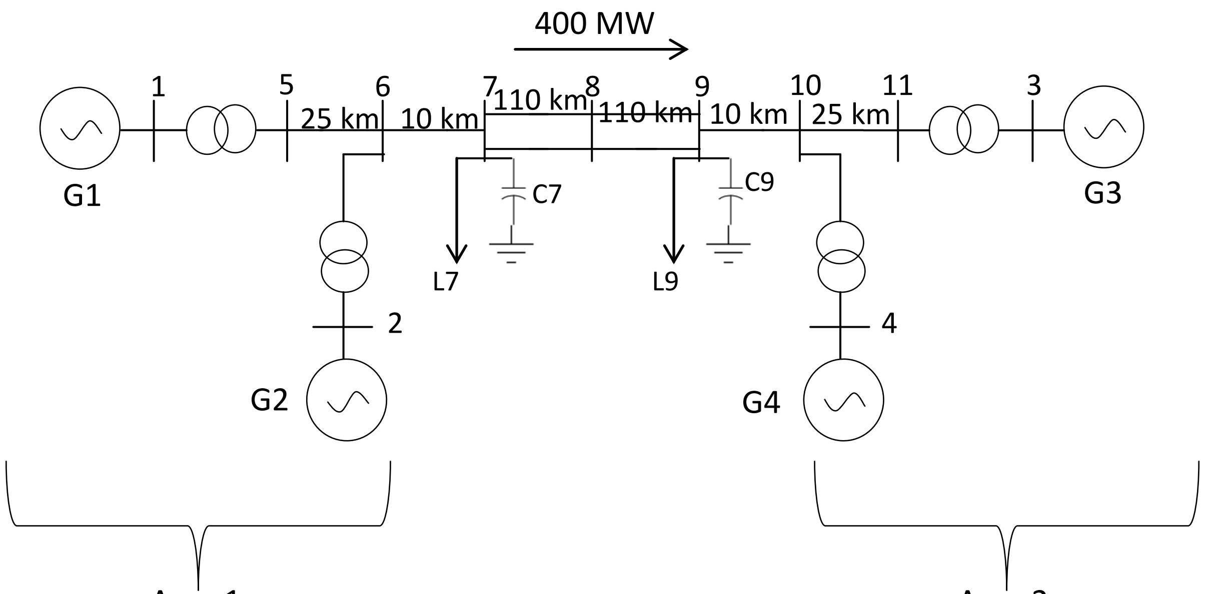

Fig 7.Two-area system line diagram [1]

Each step-up transformer has an impedance of 0+j0.15 per unit on 900 MVA and 20/230 kV, and has an off-nominal ratio of 1.0. The transmission system nominal voltage is 230 kV. The line lengths are identified in Fig.7. The parameters of the line in per unit on 100 MVA, 230 kV base are

r = 0.0001 pu/km $\qquad$ x_L= 0.001 pu/km $\qquad$ b_C= 0.00175 pu/km

The system is operating with area 1 exporting 400 MW to area 2, and the generating units are loaded as follows:

$G1: \quad P = 700\ MW, \qquad Q = 185\ MVAr, \qquad E_t = 1.03\angle 20.2^\circ$

$G2: \quad P = 700\ MW, \qquad Q = 235\ MVAr, \qquad E_t = 1.01\angle 10.5^\circ$

$G3: \quad P = 719\ MW, \qquad Q = 176\ MVAr, \qquad E_t = 1.03\angle -6.8^\circ$

$G4: \quad P = 700\ MW, \qquad Q = 202\ MVAr, \qquad E_t = 1.01\angle -17^\circ$

The loads and reactive power supplied (Q_C) by the shunt capacitors at buses 7 and 9 are as follows:

Bus 7: $P_L = 967$ *MW,* $Q_L = 100$ *MVAr,* $Q_C = 200$ *MVAr*

Bus 9: $P_L = 1{,}767$ *MW,* $Q_L = 100$ *MVAr,* $Q_C = 350$ *MVAr*

Thyristor exciter with high transient gain and PSS:

$K_A = 200.0$ $T_R = 0.01$ $K_{STAB} = 20.0$ $T_W = 10.0$

$T_1 = 0.05$ $T_2 = 0.02$ $T_3 = 3.0$ $T_4 = 5.4$

The block diagram of thyristor excitation system with PSS is shown in Fig 8.

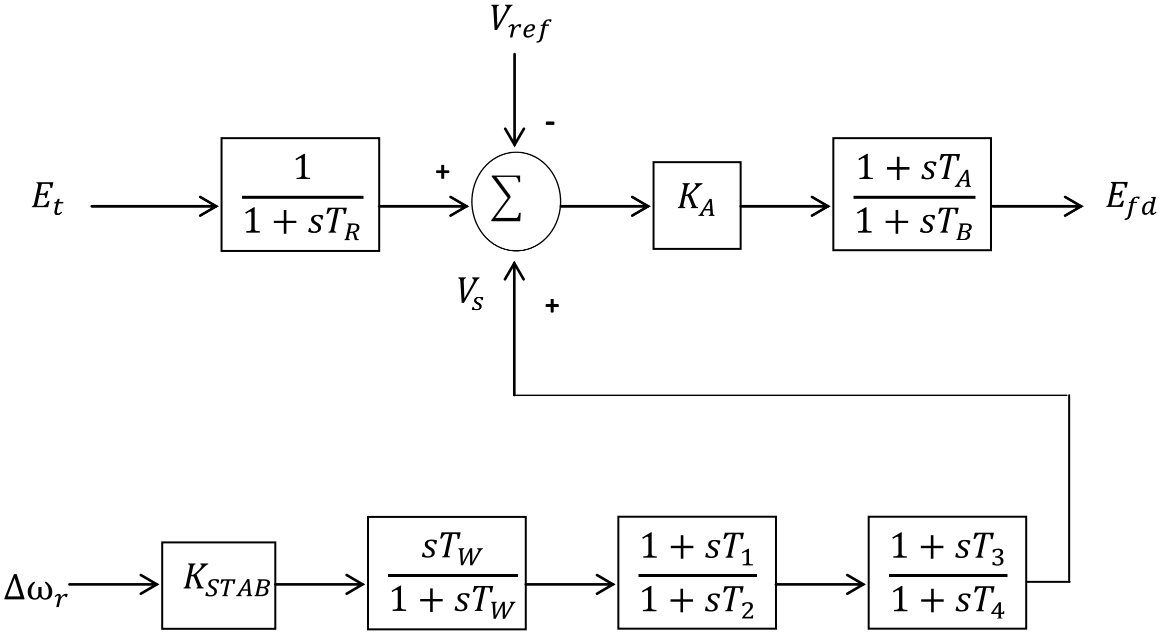

Fig 8.Thyristor excitation system with PSS [1]

4.3 <u>Linearization of A Two Area System Using PST</u>

We have used PST for linearization, which consists of a set of coordinated MATLAB m-files which models the power system components which are very necessary for power system stability and power flow studies. User manual is provided with demo examples to show how models can be used. The MATLAB file (d2Area_sys3.m) for simulation is as follows:

```
%Two Area System

%Taken from Kundur


disp('Two Area System Load Flow Studies')
```

```
% bus data format
% bus:
% col1 number
% col2 voltage magnitude(pu)
% col3 voltage angle(degree)
% col4 p_gen(pu)
% col5 q_gen(pu),
% col6 p_load(pu)
% col7 q_load(pu)
% col8 G shunt(pu)
% col9 B shunt(pu)
% col10 bus_type
%       bus_type - 1, swing bus
%               - 2, generator bus (PV bus)
%               - 3, load bus (PQ bus)
% col11 q_gen_max(pu)
% col12 q_gen_min(pu)
% col13 v_rated (kV)
% col14 v_maxpu
% col15 v_minpu

bus = [...
% No  V_magV_anglep_genq_genp_loadq_load    G    B     Type
q_gen_maxq_gen_minv_ratedv_maxv_min
  1   1.0300    20.2    0.7778   0.1985  0.00    0.00    0.00 0.00
1    1.0       -1.00     20.0    1.05  0.95;
  2   1.0100    10.5    0.7778   0.2440  0.00    0.00    0.00 0.00
2    1.0       -1.00     20.0    1.05  0.95;
  3   1.0300    -6.80   0.7989   0.1876  0.00    0.00    0.00 0.00
2    1.0       -1.00     20.0    1.05  0.95;
```

```
  4   1.0100   -17.0    0.7778   0.2055  0.00    0.00    0.00 0.00
2    1.0       -1.00     20.0    1.05  0.95;

  5   1.0075   13.7500  0.00     0.00    0.00    0.00    0.00 0.00
3    0.00        0.00     230.0    1.1  0.90;

  6   0.9806    3.7011  0.00     0.00    0.00    0.00    0.00 0.00
3    0.00        0.00     230.0    1.1  0.80;

  7   0.9654   -4.6569  0.00     0.2222  1.0744  0.1111  0.00 0.00
3    0.00        0.00     230.0    1.1  0.80;

  8   0.9539   -18.3798 0.00     0.00    0.00    0.00    0.00 0.00
3    0.00        0.00     230.0    1.1  0.90;

  9   0.9764   -31.8232 0.00     0.3889  1.9633  0.1111  0.00 0.00
3    0.00        0.00     230.0    1.1  0.80;

10  0.9863   -23.4626 0.00     0.00    0.00    0.00    0.00 0.00
3    0.00        0.00     230.0    1.1  0.80;

11  1.0094   -13.1855 0.00     0.00    0.00    0.00    0.00 0.00
3    0.00        0.00     230.0    1.1  0.90];


line = [...

%from to r(pu) x(pu) charging(pu)
tap_ratiotap_phasetapmaxtapmintapsize

 1    5   0.0  0.15     0.00       1.0      0.       0.     0.
0.;

 2    6   0.0  0.15     0.00       1.0      0.       0.     0.
0.;

 3    11  0.0  0.15     0.00       1.0      0.       0.     0.
0.;

 4    10  0.0  0.15     0.00       1.0      0.       0.     0.
0.;

 5    6  0.0025 0.025  0.04375     1.0      0.       0.     0.
0.;

 6    7  0.0010 0.010  0.01750     1.0      0.       0.     0.
0.;

 7    8  0.0110 0.110  0.1925      1.0      0.       0.     0.
0.;

 7    8  0.0110 0.0110 0.1925      1.0      0.       0.     0.
0.;
```

```
 8    9  0.0110 0.110  0.1925       1.0       0.        0.      0.
0.;

8    9   0.0110 0.110 0.1925        1.0       0.        0.      0.
0.;

9    10  0.0010 0.010 0.0175        1.0       0.        0.      0.
0.;

10   11  0.0025 0.025 0.00175*25    1.0       0.        0.      0.
0.];


Zbase_100_230=230^2/100;

Zbase_900_230=230^2/900;

line(5:12,3:4)=line(5:12,3:4)*Zbase_100_230/Zbase_900_230;

line(5:12,5)=line(5:12,5)*Zbase_900_230/Zbase_100_230;


% Machine data format

%       1.machine number,

%       2.bus number,

%       3.basemva,

%       4.leakage reactance x_l(pu),

%       5.resistancer_a(pu),

%       6.d-axissychronous reactance x_d(pu),

%       7.d-axis transient reactance x'_d(pu),

%       8.d-axissubtransient reactance x"_d(pu),

%       9.d-axis open-circuit time constant T'_do(sec),

%      10.d-axis open-circuit subtransient time constant

%                T"_do(sec),

%      11.q-axissychronous reactance x_q(pu),

%      12.q-axis transient reactance x'_q(pu),

%      13.q-axissubtransient reactance x"_q(pu),

%      14.q-axis open-circuit time constant T'_qo(sec),
```

```
%       15.q-axis open circuit subtransient time constant
%                 T"_qo(sec),
%       16.inertia constant H(sec),
%       17.damping coefficient d_o(pu),
%       18.dampling coefficient d_1(pu),
%       19.bus number
mac_con = [1 1 900 0.200 0.0025 1.8 0.55 0.25 8.00 0.03 1.7 0.55
0.25 0.4 0.05 6.500 0 0 1 0.0625  0.2083;
           2 2 900 0.200 0.0025 1.8 0.55 0.25 8.00 0.03 1.7 0.55
0.25 0.4 0.05 6.500 0 0 2 0.0625  0.2083;
           3 3 900 0.200 0.0025 1.8 0.55 0.25 8.00 0.03 1.7 0.55
0.25 0.4 0.05 6.175 0 0 3 0.0625  0.2083;
           4 4 900 0.200 0.0025 1.8 0.55 0.25 8.00 0.03 1.7 0.55
0.25 0.4 0.05 6.175 0 0 4 0.0625  0.2083];


load_con = [7 0 1 1 0;%constant impedance
            9 0 1 1 0;];


%    COL     VARIABLE
%    1.exciter type (0-simple exciter)
%    2.generator number
%    3.transducer filter time constant T_R (sec)
%    4.voltage regulator gain K_A (pu)
%    5.voltage regulator time constant T_A (sec)
%    6.transient gain reduction time constant T_B (sec)
%    7.transient gain reduction time constant T_C (sec)
%    8.maximum voltage regulator output V_Rmax  (pu)
%    9.minimum voltage regulator output V_Rmin  (pu)
%
exc_con = [0   1   0.01  200   0   0   0   1.05   -0.90;...
```

```
            0   2   0.01  200   0   0   0   1.05   -0.90;...
            0   3   0.01  200   0   0   0   1.05   -0.90;...
            0   4   0.01  200   0   0   0   1.05   -0.90];
% %pss_con data format
% %   COL     VARIABLE
% %   1.type, 1-speed_input or 2-power_input
% %   2.machine number
% %   3.gain K
% %   4.washout time constant T (sec)
% %   5.lead time constant T_1 (sec)
% %   6.lag time constant T_2 (sec)
% %   7.lead time constant T_3 (sec)
% %   8.lag time constant T_4 (sec)
% %   9.maximum output limit (pu)
% %   10.minimum output limit (pu)
%
pss_con = [1  1  200  10  0.05  0.02  3  5.4  0.15  -0.15;...
           1  2  200  10  0.05  0.02  3  5.4  0.15  -0.15;...
           1  3  200  10  0.05  0.02  3  5.4  0.15  -0.15;...
           1  4  200  10  0.05  0.02  3  5.4  0.15  -0.15];

% governor model
% tg_con matrix format
%column        data         unit
% 1    turbine model number (=1)
% 2    machine number
% 3    speed set point   wfpu
% 4    steady state gain 1/R       pu
% 5    maximum power order  Tmaxpu on generator base
```

```
%  6    servo time constant   Ts    sec
%  7    governor time constant  Tc  sec
%  8    transient gain time constant T3 sec
%  9    HP section time constant   T4   sec
% 10    reheater time constant    T5    sec

% row 1 col1  simulation start time (s) (cols 2 to 6 zeros)
%       col7  initial time step (s)
% row 2 col1  fault application time (s)
%       col2  bus number at which fault is applied
%       col3  bus number defining far end of faulted line
%       col4  zero sequence impedance in pu on system base
%       col5  negative sequence impedance in pu on system base
%       col6  type of fault  - 0 three phase
%                            - 1 line to ground
%                            - 2 line-to-line to ground
%                            - 3 line-to-line
%                            - 4 loss of line with no fault
%                            - 5 loss of load at bus
%                            - 6 no action
%       col7  time step for fault period (s)
% row 3 col1  near end fault clearing time (s) (cols 2 to 6 zeros)
%       col7  time step for second part of fault (s)
% row 4 col1  far end fault clearing time (s) (cols 2 to 6 zeros)
%       col7  time step for fault cleared simulation (s)
% row 5 col1  time to change step length (s)
%       col7  time step (s)
%
%
```

```
%
% row n col1 finishing time (s)  (n indicates that intermediate rows may be inserted)

sw_con = [0 0 0 0 0 0 0.01;%sets initial time step
0.1 3 101 0 0 6 0.01; % no fault
0.15 0 0 0 0 0 0.01; %clear near end
0.20 0 0 0 0 0 0.01; %clear remote end
15.0 0 0 0 0 0 0]; % end simulation];
```

Running s_simu and choosing the file d2Area_sys3, simulates a three-phase fault at bus 7 on the first line from bus 7 to bus 8. The fault is cleared at bus 7 0.01s after the fault is applied, and at bus 8 0.02 s after the fault is applied. The results are shown below:

s_simu

non-linear simulation

Two Area System Load Flow Studies

enter the base system frequency in Hz - [60]

enter system base MVA – [900]

Do you want to solve loadflow> (y/n)[y]

inner load flow iterations

2

tap iterations

1

Performing simulation.

constructing reduced y matrices

initializing motor, induction generator, svc and dc control models

initializing other models

generators

generator controls

non-linear loads

elapsed time = 40.5709s

You can examine the system response

Type 1 to see all machine angles in 3D

  2 to see all machine speed deviation in 3D

  3 to see all machine turbine powers

  4 to see all machine electrical powers

  5 to see all field voltages

  6 to see all bus voltage magnitude in 3D

  7 to see the line power flows

  0 to quit and plot your own curves

enter selection >>

As the simulation progresses, the voltage at the fault bus (bus 7) is plotted. The final response is shown in Figure 9.

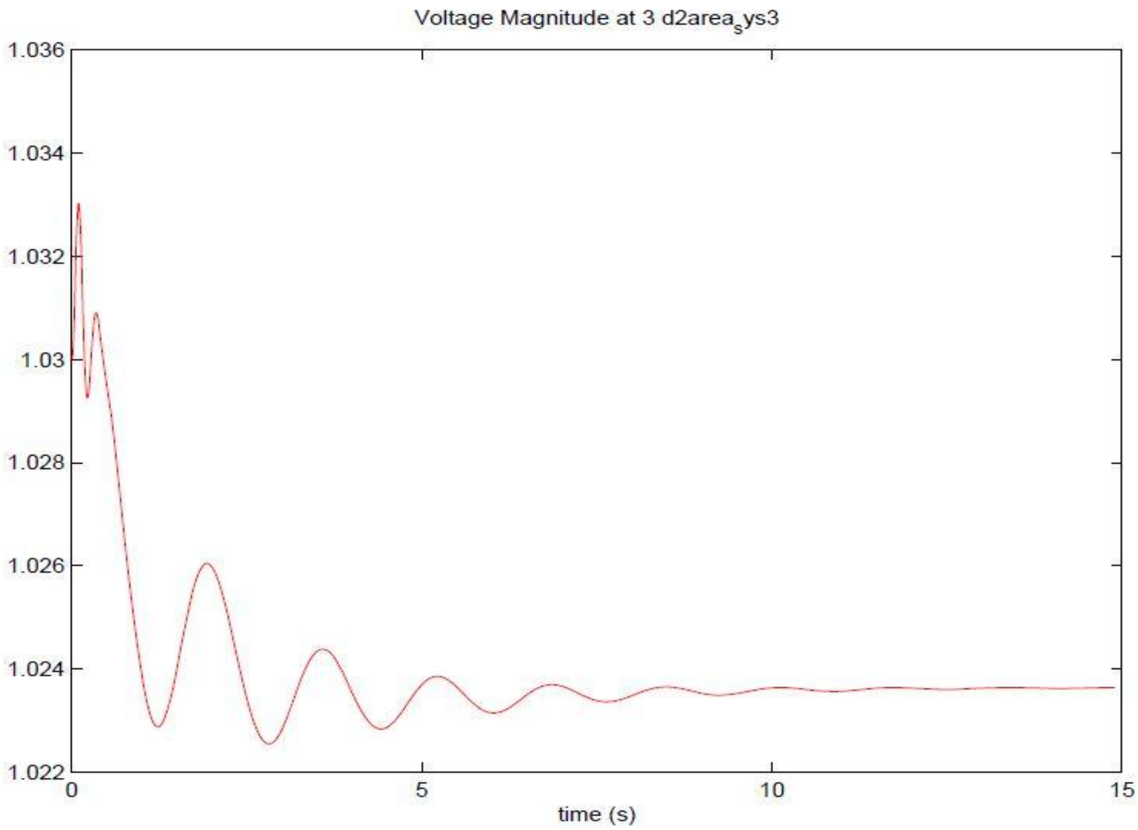

Fig 9. Voltage magnitude response to three-phase fault

Using the same file used above, now running svm_mgen and choose the file d2Area_sys3, we got the result as shown below:

svm_mgen

linearized model development by perturbation of the non-linear model

Two Area System Load Flow Studies

enter the base system frequency in Hz - [60]

enter system base MVA – [900]

Do you wish to perform a post load flow test?Y/N[Y]

enter the changes to bus and line required to give the post fault condition

when you have finished, type return and press enter

K>> return

Do you want to solve loadflow> (y/n)[y]

inner load flow iterations

2

tap iterations

1

Performing linearization

non-linear loads

disturb generator

disturb simple exciter

disturb pss

disturb V_ref

disturb generator

disturb simple exciter

disturb pss

disturb V_ref

disturb generator

disturb simple exciter

disturb pss

disturb V_ref

disturb generator

disturb simple exciter

disturb pss

disturb V_ref

calculating eigenvalues and eigenvectors

Current plot held

Running svm_mgen (svm_mgen which forms the state matrices of a power system model, linearized about an operating point set by a load flow andperforms modal analysis) gives:

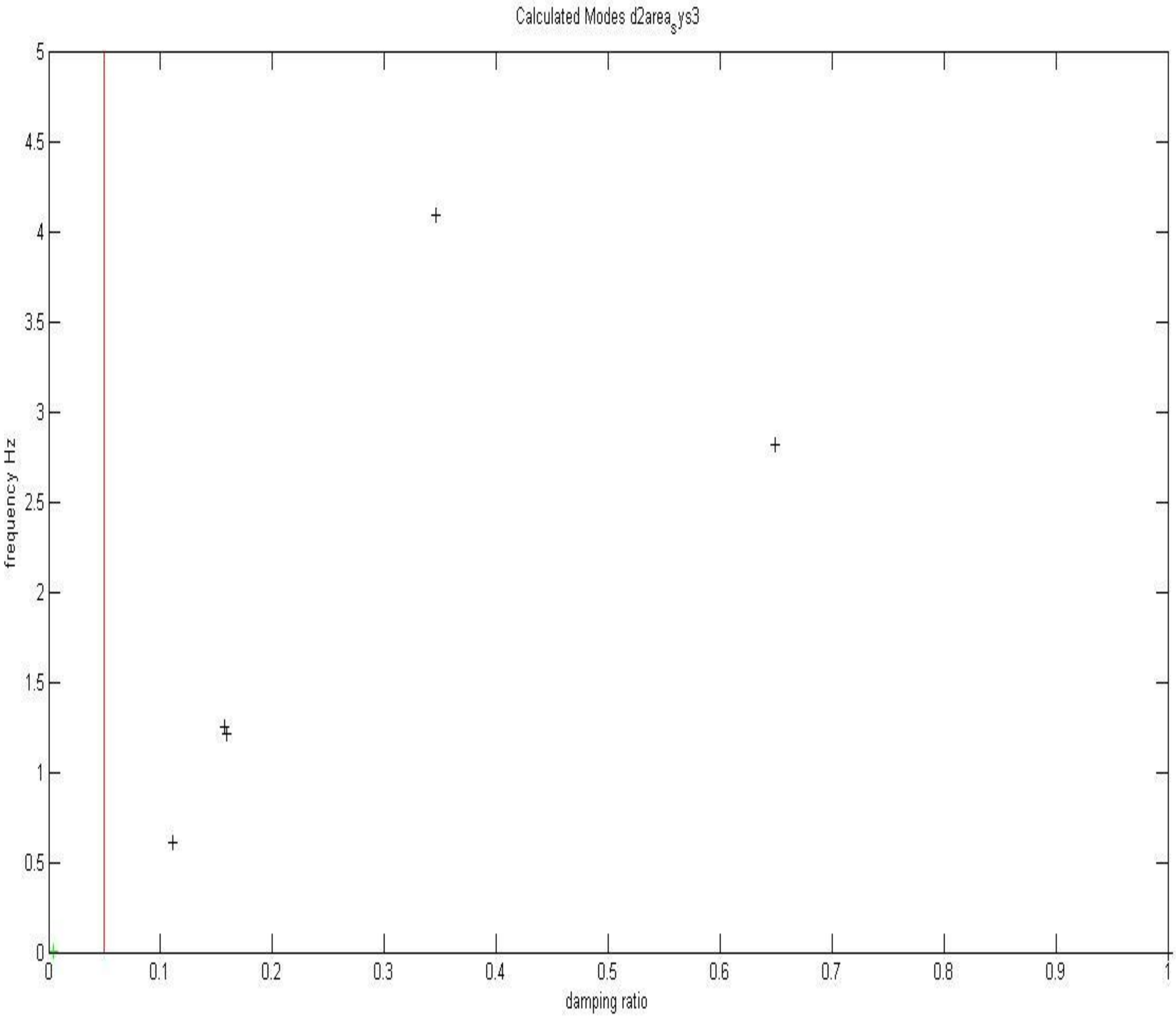

Fig 10. Calculated modes of d2Area_sys3

The MATLAB Workspace after running svm_mgen is shown in Figure 11.

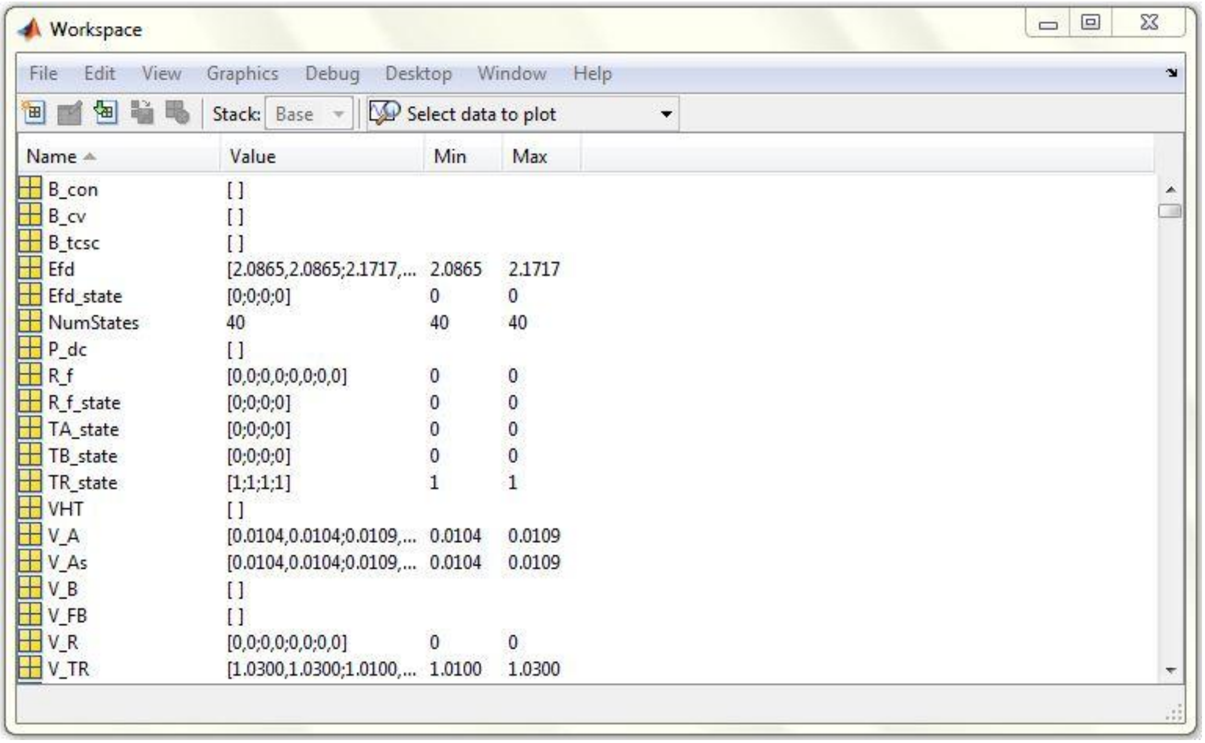

Fig 11.The MATLAB Workspace following a run of svm_mgen

The eigenvalues damping ratios and frequencies of the modes may be obtained using

[l damp freq]

ans =

1.0e+002 *

-0.0000 - 0.0000i	0.0000	0.0000
-0.0000 + 0.0000i	0.0000	0.0000
-0.0010	0.0100	0
-0.0010	0.0100	0
-0.0010	0.0100	0
-0.0018	0.0100	0
-0.0018	0.0100	0

-0.0018	0.0100	0
-0.0044	0.0100	0
-0.0064	0.0100	0
-0.0290	0.0100	0
-0.0294	0.0100	0
-0.0353	0.0100	0
-0.0365	0.0100	0
-0.0043 - 0.0384i	0.0011	0.0061
-0.0043 + 0.0384i	0.0011	0.0061
-0.0123 - 0.0760i	0.0016	0.0121
-0.0123 + 0.0760i	0.0016	0.0121
-0.0125 - 0.0782i	0.0016	0.0125
-0.0125 + 0.0782i	0.0016	0.0125
-0.0882	0.0100	0
-0.0905	0.0100	0
-0.1512 - 0.1772i	0.0065	0.0282
-0.1512 + 0.1772i	0.0065	0.0282
-0.0948 - 0.2571i	0.0035	0.0409
-0.0948 + 0.2571i	0.0035	0.0409
-0.3040	0.0100	0
-0.3144	0.0100	0
-0.3528	0.0100	0
-0.3574	0.0100	0

-0.3872	0.0100	0
-0.3915	0.0100	0
-0.5034	0.0100	0
-0.5050	0.0100	0
-0.5263	0.0100	0
-0.5285	0.0100	0
-1.0338	0.0100	0
-1.0344	0.0100	0
-1.0457	0.0100	0
-1.0527	0.0100	0

The values obtained above after simulation is in close approximation with the calculated results from the Prabha Kundur book. All eigenvalues, apart from the theoretically zero eigenvalue, have negative real parts, i.e, the system is stable. In the plot of frequency against damping ratio, the damping ratio of the effectively zero eigenvalue is taken as one, if its magnitude is less than 10^{-4}.

CHAPTER 5

PSS DESIGN USING PST

5.1 Introduction:

The generator rotor states should be removed in a system model to design a power system stabilizer. The input to the system is the voltage reference of the generator at which the power system stabilizer is to be placed. The output is the generator electrical power [8].

5.2 Design: Simulation and Results

For designing PSS for Kundur's two area system we have used the same MATLAB file as in Chapter 4, and making pss_con as null matrix i.e. disabling the PSS and running svm_mgen in MATLAB gives:

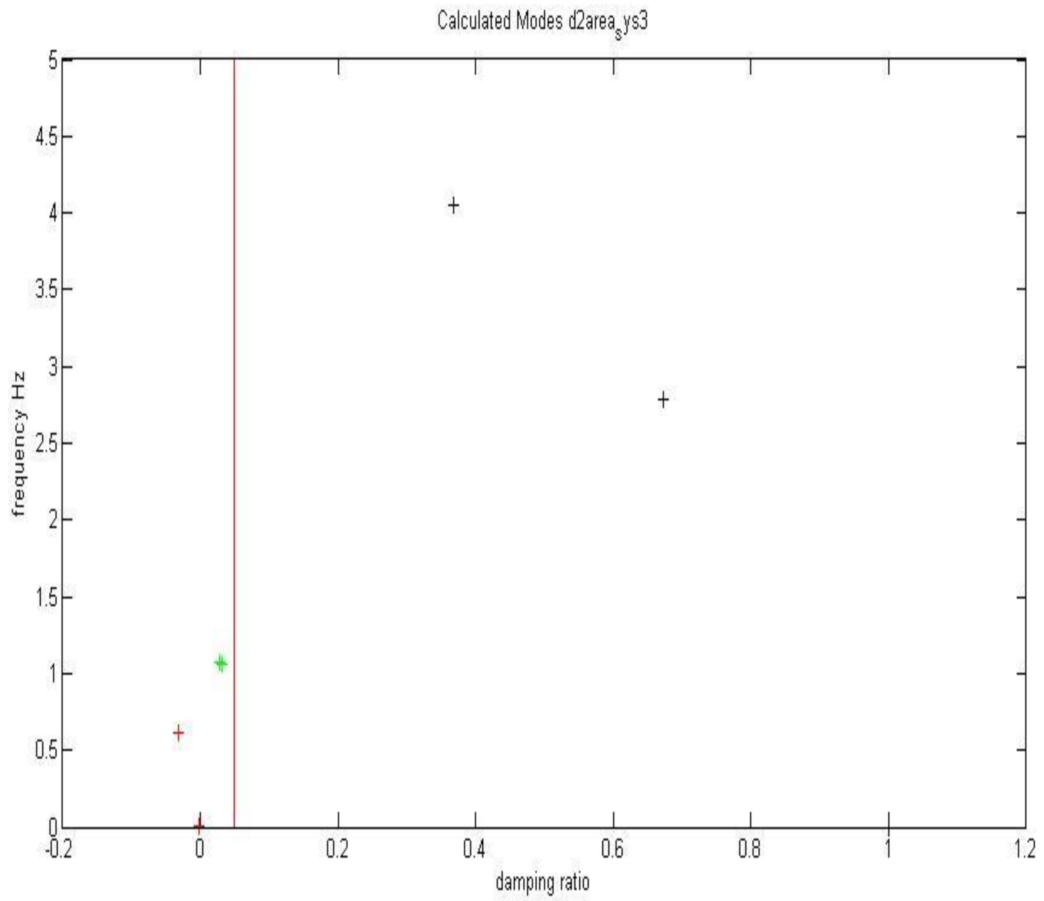

Fig 12.Modes of two-area system with exciters and governors on all units

The above figures shows the inter-area mode is unstable +.

For designing the PSS we have used the m-file (pss_des.m) from PST and simulated in MATLAB and the results and command are shown below:

```
>> a=a_mat; b=b_vr(:,1); c=c_p(1,:); d=0;
>>ang_idx = find(mac_state(:,2)==1)
ang_idx =
    1
    8
   15
   22
>>rot_idx = sort([ang_idx;ang_idx+1])
rot_idx =
    1
    2
    8
    9
   15
   16
   22
   23

>> a(rot_idx,:)=[]; a(:,rot_idx)=[];
>>b(rot_idx)=[];
>>c(rot_idx)=[];
>>spssd = ss(a,b,c,d);
```

The ideal power system stabilizer phase lead is given by the negative of the response of spssd. This is obtained using

```
f = linspace(.1, 2);
[f,ympd,yapd]=fr_stsp(spssd,f);
plot(f,-yapd)
```

The plot for the ideal power system stabilizer phase lead versus frequency is obtained and found to be approximately a straight line as shown in Figure 13.

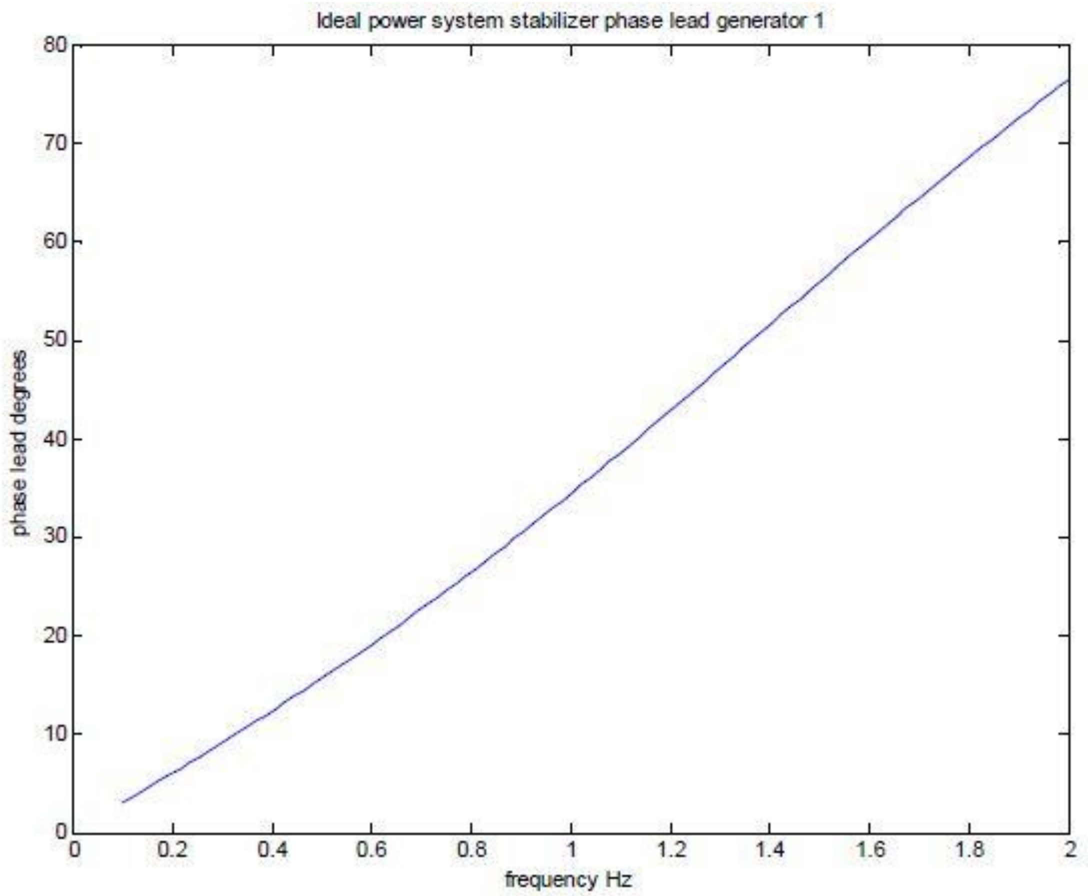

Fig 13. Ideal power system stabilizer phase lead

The pss_des.mallows trial and error determination of PSS parameters to fit an ideal frequency response having syntax

[tw,t1,t2,t3,t4] = pss_des(a,b,c,d,rot_idx)

Where,

a the state matrix of the system for which the PSS is to be designed

b the input matrix associated for the exciter reference input

c the output matrix associated with the generator mechanical torque

d the feed forward matrix between the voltage reference and the generator mechanical torque. Normally zero

tw the washout time constant (s)

t1 the first lead time constant (s)

t2 the first lag time constant (s)

t3 the second lead time constant (s)

t4 the second lag time constant (s)

This algorithm is implemented in the M-file **pss_des** in the POWER SYSTEM TOOLBOX.

```
>>[tw,t1,t2,t3,t4] = pss_des(a,b,c,d)
enter the start frequency (Hz) [0.1]
enter the frequency step (Hz) [0.01]
enter the end frequency (Hz) [2.0]
input the washout time constant in secs:[5]10
the first lead time constant in secs:[.2]0.07
the first lag time constant in secs:[.02]
the second lead time constant in secs:[.2]0.07
the second lag time constant in secs:[.02]
Do you wish to try another pss design: Y/N[Y]N
```

The plot is shown below

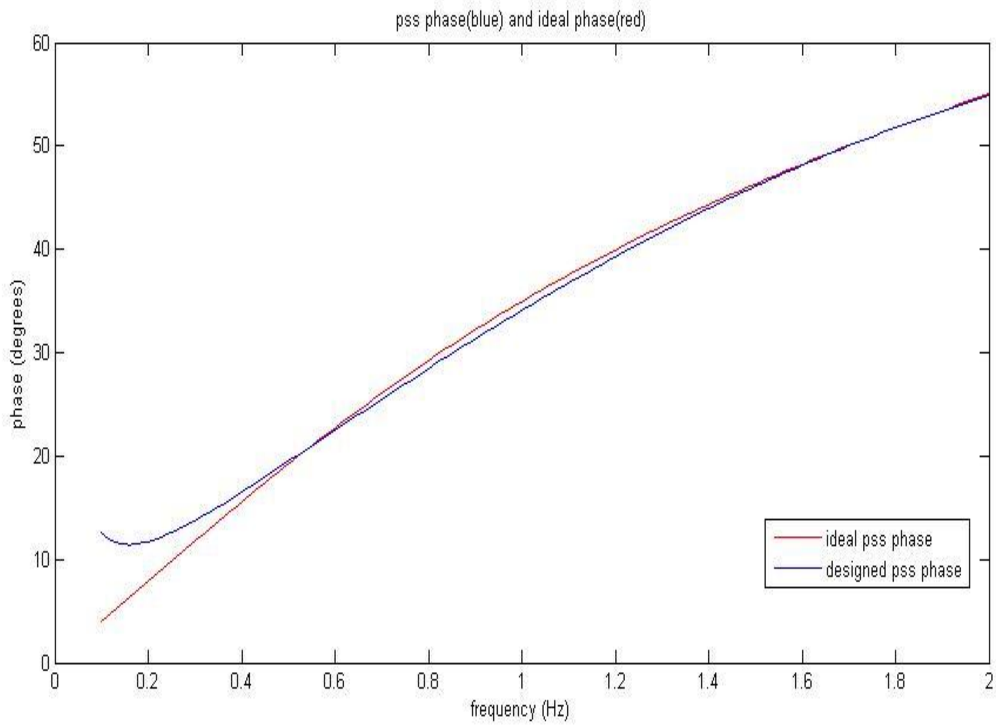

Fig 14.Ideal PSS Phase and Designed PSS Phase Lead

Figure 14 shows that the power system stabilizer phase lead and the ideal phase lead are sufficiently close.

CHAPTER 6

CONCLUSION

6.1 Conclusion:

The extensive study on two area system problem given in ‘kundur’ book is carried out and it is found that the stability problem arising in it is solved. The critical parameters like damping ratios, frequencies and graphs of voltage magnitudes at faulty bus 7 shows that the system works in a steady state as well as transient stable mode. All the simulated results are in close accordance with the theoretically calculated results in the book. The graphs involved show that the ideal and non-ideal PSS design results coincide closely. The optimal design of Power System Stabilizer (PSS) involves a deep understanding of the dynamics of the single machine infinite bus system. So we have obtained the state space model of a single machine infinite bus system and modelled the linear model of single machine infinite bus system. The linear model for Kundur’s two area system is obtained using POWER SYSTEM TOOLBOX, using svm_mgen which forms the state matrices of a power system model, linearized about an operating point set by a load flow and performs modal analysis. To obtain transient stability s_simu from PST is used, which acts as driver for transient simulation. The svm_mgen and s-simu drivers simulation give successful steady state and transient models respectively.

6.1 Future Work:

In this project we have designed PSS for two area system each area consisting of two generators. The same can be extended to more area system or for a larger system. The work done in this project forms the base for larger power system networks.

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[9] http://www.montefiore.ulg.ac.be/~vct/elec047/angstab-def.pdf

APPENDIX

1. The power system model

The state equations are:-

$\Delta x' = A\Delta x + B\Delta u$

$\Delta y = C\Delta x + D\Delta u$

Where state variables x = [δ ω $E_q' \Psi_d E_d' \Psi_q V_r$]^T

Output variables y = [$V_{term} \omega$ P_e]^T

Input variable u = V_{ref}

Where, δ = rotor angle in radian.

Ω = angular frequency in radian/sec

$E_d' \Psi_d$= direct axis field and flux

$E_q' \Psi_q$ = quadrature axis field and flux

V_{term}= terminal voltage

P_e= Power delivered to the infinite bus.

$$A = \begin{bmatrix} -0.143K_D & -0.108 \\ 377 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.143 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

2. Symbols Used

X_m = Magnetizing reactance

X_l = Stator leakage reactance

X_r = Rotor leakage reactance

R_r = Rotor resistance

R_a = Stator resistance

s = Slip

X_d = Synchronous reactance

X_q = Quadrature axis reactance

X''_d = Sub-transient reactance

X'_d = Transient reactance

X_0 = Zero sequence reactance

X_2 = Negative sequence reactance

R_0 = Zero sequence resistance

R_2 = Negative sequence resistance

T_w = Washout filter time constant

T_1 = First lead time constant

T_2 = First lag time constant

T_3 = Second lead time constant

T_4 = Second lag time constant